EVALUATION OF A THREE-BEAM VEHICLE LIGHTING SYSTEM

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One near-term improvement for vehicle forward lighting is a 3-beam 4-head-lamp system. This system, which includes a high and low beam with increased intensities and a moderately high-intensity midbeam, should provide increased seeing distance. This paper describes the results of a 3-phase evaluation of various combinations of beam usages to achieve the 3 modes. A computer program calculated the glare in the rearview mirror as a following vehicle with different headlighting systems approached from the rear. The results show very minor differences in glare among any of the beam configurations on the same mode. Vehicles equipped with the 3-beam systems were driven by a sample of drivers under a representative sample of road and traffic conditions. An evaluation of the subjective responses of the drivers to the system was made, and objective measures of the traffic stream's responses (through dimming requests) were recorded. There were slight differences in the number of dimming requests among the various configurations, and the drivers subjectively favored the use of a midbeam mode but were unable to select 1 high-beam system as superior. The last phase of this program was an empirical determination of seeing distances. The results of this phase showed that a beam configuration using all 4 head lamps in the high-beam mode yielded better seeing distances than others. The high-beam mode using all 4 head lamps appears to be the best configuration of those tested because it does not represent excessive glare and does not yield greater dimming requests, but does yield greater seeing distances.

•THE IMPORTANCE of providing the motor vehicle driver with a clear field of view under varying lighting and other environmental conditions has been pointed out by many investigators. Byrnes (1) indicates that 90 percent of the driver's information is visual. King and Lunenfeld (2) point out that the driver scans a dynamically changing environment searching for information to predict what will occur next. Anything leading to the driver's inability to obtain needed information may lead to missed information and errors. This contributes to the majority of motor vehicle accidents (3). Examination of accident records shows that the majority of fatalities (53 percent) as well as the highest death rate (8.7 per 100 million miles) occur at night (4). Although many factors contribute to this higher night fatality rate (for example, alcohol and fatigue), reduced visibility is the obvious factor according to Schmidt and Connolly (5).

The problem of improving night vision is illuminating the traveled way ahead while minimizing glare effects on the oncoming driver and rearview mirror glare on drivers upstream. Some research has been done in these areas with a diversity of approaches. Research done for the Federal Highway Administration (FHWA) indicates some technical advantages for polarization of headlights (6).

The National Safety Council (NSC) has, over the years, warned U.S. drivers of overdriving their headlights by excessive speed. Because of reduced forward vision at night the driver cannot see the object before it is too late to brake. Of the various schemes of forward lighting presented, most tend to be long range. One short-range program,

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suggested by Hull et al. (7) in a study for the National Highway Traffic Safety Administration (NHTSA), is a recommended 3-beam, 4-head-lamp system to resolve these night vision problems. The NHTSA has called for the development of a 3-beam forward lighting system for a 4-lamp vehicle to be a short-range improvement in night visibility. This system, which represents a new approach in vehicle lighting systems, would provide drivers with 3, rather than 2, beam selections with higher intensities and increased seeing distances in each mode. From a safety point of view, this system must ultimately lead to safer night driving.

This paper describes the results of a threefold series of experiments whose aim was a partial analysis of the efficacy of different 3-beam modes. The first evaluation was done by using a computer program that calculated the glare in the rearview mirror as a following vehicle with different headlight systems approached from the rear. The computer program had flexibility to calculate the glare brightness for many isocandela distributions and numerous vehicular positions, road alignments, and head-lamp configurations. A field experiment was conducted to validate the computer results. The second phase was a subjective series of field evaluation experiments where 6 untrained operators drove different test vehicles for a number of nights. Surveys by questionnaire were conducted before, between, and after the experiments, and an analysis of the human factors associated with the operation of the system was done for subjective evaluation. At the same time, an objective evaluation of the system performance was done by counting the number of dimming requests by the opposing traffic. The third phase of the program was an empirical evaluation based on sight-distance experiments. These experiments had a number of drivers driving vehicles on different beam modes. Their goal was to detect and record the positions of targets randomly arranged on the roadside.

The final project report (8) contains a comprehensive account of the experiments and results that were extracted for this paper.

EVALUATION METHODOLOGY

The need for increasing light coverage (lamp intensity or road illumination), without increasing the glare to oncoming drivers, leads to improving vehicle headlight systems. Of the various improved systems proposed, 3 configurations incorporating combinations of tungsten-filament head lamps were studied. The 3 configurations, shown in Figure 1, add a third intermediate beam for driving on expressways. The midbeam filament (B, Fig. 1) is a compact directional beam on the driver's side of the vehicle. This head lamp is aimed at the horizontal and adds more light straight ahead and farther down the road. Thus, in cases when high beams are unusable, the additional light from this midbeam reduces the effect of overdriving the headlights. The scope of study in this program was the evaluation of the three 3-beam configurations—2-3-2, 2-3-3, and 2-3-4, as shown in Figure 1.

Analytical Techniques

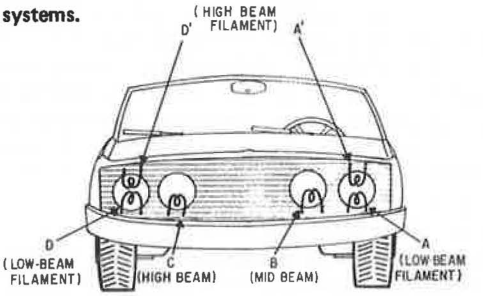
The analytical techniques used in glare computation are similar to techniques previously used in studying the brightness of highway signs (9). The computer program determines the amount of light leaving each head lamp in the direction of the mirror. It then calculates the glare intensity at the mirror and accounts for many variables inserted in the program such as reflectivity of the mirror, and transmission through the rearview mirror.

Empirical Techniques

Both subjective field evaluation and sight-distance experiments require collection of empirical data. So, a number of cars must be modified for 3-beam headlight systems with new head lamps, wire harnesses, and switches.

Instrumentation—Six leased vehicles—green Plymouth Fury III, 4-door sedans with similar options—were modified for the experiments. Two vehicles were equipped with 2-3-2 configuration, 2 with the 2-3-3 configuration, and 2 with the 2-3-4 configuration.

Figure 1. Filament use for 3-beam systems.



CONFIGURATION	BEAM MODE: LOW	BEAM MODE: MID	BEAM MODE: HIGH
2-3-2	A D	A B D	B C
2-3-3	A D	A B D	A' C D'
2-3-4	A D	A B D	A' B C D'

Figure 2. Installation in vehicle.

switches in passenger compartment

relays in engine compartment

headlamps and wiring

The head lamps were supplied to the Airborne Instruments Laboratory (AIL) by Westinghouse Electric Corporation and General Electric Company. Because there were 2 vehicles each with 2-3-2, 2-3-3, and 2-3-4 head-lamp configurations, 1 series of cars was equipped with lamps from 1 company and the other series of cars with lamps from the other. Both manufacturers were requested to supply lamps that conformed to NHTSA HS-800-529 (7).

Figure 2 shows the physical relationships of the components. A small auxiliary panel attached to the dash near the passenger's seat is shown in Figure 2. On this panel is a switch for turning the lights on and off and a 3-position rotary switch for selecting beam mode. Above the switches are 3 panel lights for the individual beam modes. When the selector switch is on low beam, a green light is illuminated; on midbeam an amber light is illuminated; and on high beam a blue light is illuminated. Figure 2 also shows the relays mounted on the inside tire well in the engine compartment and connected to the switches through the car's fire wall. From the relays, a harness of new wires was attached to the head lamps. The present head-lamp system was disconnected by uncoupling the present socket, and the new head lamps were connected to the new harness through new sockets. The head lamps and harness are also shown in Figure 2.

Aiming—The head lamps were aimed with a mechanical aimer and then checked visually on a target 25 ft away according to requirements:

1. Low beam—The upper and left edge of the highest intensity area shall be at the horizontal and vertical axes respectively of the mechanical center of the lamp;
2. Intermediate beam—The upper edge of the high-intensity zone shall be $1\frac{1}{2}$ in. above the horizontal axis and 5 in. to the left of the vertical axis of the lamp; and
3. High beam—The center of the high-intensity zone shall be at the center of the horizontal and vertical axes of the lamp.

ANALYTIC DETERMINATION OF GLARE BRIGHTNESS

The vehicle's forward lighting system should be changed only if it can aid the driver and if the change can be accomplished without being detrimental to other drivers on the road. Thus, a study of the 3-beam forward lighting system and its effect as a glare-producing source as seen on the rearview mirror of the preceding car was conducted. Configurations, beam modes, and other parameters were varied as the vehicle approached from the rear.

Analytic Methods

Glare on the rearview mirror is determined by computing the output of each head lamp directed to the mirror, the reduction of light that reaches the mirror as a function of Allard's law (I/d^2), transmission through the rear window, and reflectivity of the inside and outside rearview mirrors. A computer program, first developed under NCHRP Research Project 3-12 to determine the brightness of highway signs for many of the same parameters, was adapted to determine rearview mirror glare by substituting mirror for sign.

The program, written in FORTRAN IV for the IBM 360/75 computer, H-level compiler, began the calculation by determining the oblique distance between each headlight and the mirror on the vehicle in front of it. The horizontal and vertical beam angles were then computed trigonometrically from the horizontal and vertical components of the headlight beam. These angles were used as indexes for determining the candela output of each head lamp in the direction of the mirror. These values were entered into an isocandela distribution chart, and linear interpolations were made for intermediate values.

The final illuminance on the mirror is the sum of the individual illuminances from each head lamp and is determined from the following equation:

$$\text{Illuminance} = K \frac{\text{candela output} \times \text{reflectivity}}{(\text{oblique distance})^2}$$

The complete program (REARVU) description and listing can be found in the final report (8).

Computer Results

The results of more than 300 test cases were analyzed by the computer. The result presented here is the total maximum glare, in footcandles, from both inside and outside rearview mirrors. The graphs were plotted on log-log scales because the response of the eye is logarithmic.

Figure 3 shows a sample plot of low-beam, midbeam, and 3 high-beam configurations for a vehicle on a straight road. The 2-3-4 and 2-3-3 high-beam modes were almost identical and, to the human eye, were imperceptible; both were higher than the 2-3-2 high beam. At maximum values, the 2-3-4 high beam produced about 14 ft-c and the 2-3-2, about 6. These values were extraordinarily high, but they represent high-glare sources from a car following from 50 to 75 ft away. At about 400 ft, these values were approximately 1.0 and 0.6 ft-c respectively, which is more tolerable.

The midbeam mode produced a maximum of about 1.3 ft-c of illuminance from 50 ft. The maximum glare intensity was perceived when the driver looked directly into a rearview mirror. As can be seen by the curve, the values for the midbeam mode were not much more than those of the low-beam mode.

SUBJECTIVE FIELD EVALUATION

The primary purpose of the 3-beam headlight systems evaluated in this study is to enhance forward night vision to make night driving safer, more comfortable, and more efficient. An evaluation must take into account, in addition to the objective factors pertaining to the physical operation of the system, those subjective human factors associated with its operation by the driver. And, because the driver is a part of the overall highway system of roads, traffic and environments, these subjective human factors must be evaluated in relation to the highway system. The purpose of this phase of the study, a limited on-site evaluation, was to determine how average drivers subjectively evaluate the system to provide an indication of user acceptance and user ratings. The purpose of this phase was also to determine how the traffic stream responds to headlight glare to provide an indication of the interaction of various headlight configurations with opposing and preceding drivers.

These aims required that vehicles equipped with 3-beam systems be driven by a sample of drivers under a representative sample of road and traffic conditions. In the course of these drives, an evaluation of the subjective responses of the drivers to the system was elicited and objective measures of the traffic stream's responses (through dimming requests) were recorded.

Site and Route Selection

To fulfill the requirements of the subjective field evaluation phase, it was necessary to select a test route that would provide a representative mix of road, traffic, and land use characteristics that would be encountered in normal nighttime driving situations.

A circular intersecting test route incorporating the independent variables was selected. The route, from start to finish, took 2 hours driving time so 2 circuits, 1 in each direction, provided the 4-hour exposure time. A midsession break was also provided so that the drivers could rest and so that subjective data could be taken.

Subject Selection

Six subjects, each of whom would drive a different test vehicle each of the 3 nights to evaluate all 3 systems, were hired. These drivers were not to be technically oriented and were close to the representative of the medium case driver so that extremes in age, experience, vision, and the like would be controlled. And, selection was based on whether the driver could relate to the situation and be able to talk about it.

The subject driver was an average of 30.7 years of age, had been driving for an average of 13.8 years, and drove an average of 16,000 miles per year. At the beginning of the interviewing session, drivers were given a preevaluation questionnaire to fill out before the new headlight systems were tested. The subjects were assigned to vehicles, systems, sessions, and routes on a random basis to control for order effects.

Figure 3. Straight road glare intensity.

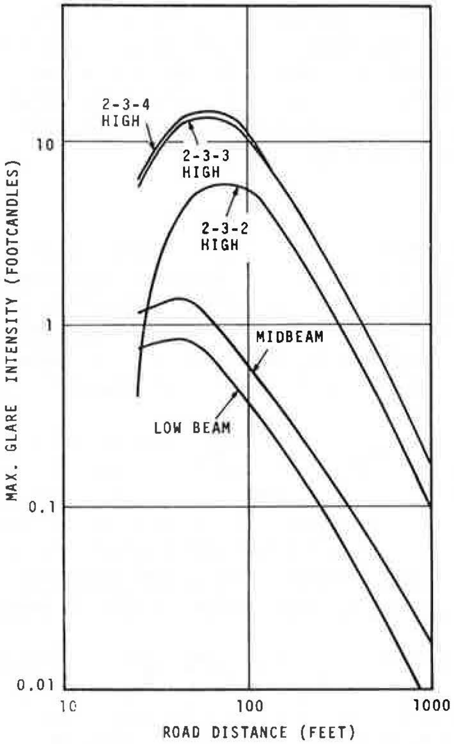


Figure 4. Systems evaluation profile analysis.

LAND USE	ROAD TYPE	TRAFFIC CONDITIONS	ROAD LIGHTS	ROAD GEOMETRY	BEAM USAGE	DIMMING REQUEST FACTOR 2-3-2	2-3-3	2-3-4
2-LANE	URBAN	LIGHT	MOSTLY LIT	STRAIGHT	LOW MID HIGH	0.47 0.00 0.00	1.49 0.00 0.00	0.53 0.00 0.00
2-LANE	RURAL	LIGHT	UNLIT	HILLY-CURVED	LOW MID HIGH	5.68 9.09 14.88	5.09 12.80 19.63	0.00 6.92 13.60
4-LANE	URBAN	LIGHT TO MEDIUM	SOME LIGHTS	STRAIGHT	LOW MID HIGH	0.00 4.18 8.33	0.00 0.89 0.00	0.00 0.38 0.00
4-LANE	RURAL	LIGHT	UNLIT	STRAIGHT	LOW MID HIGH	0.00 1.71 5.79	0.00 0.61 8.63	0.00 1.52 13.39
>4-LANE	URBAN	LIGHT TO MEDIUM	UNLIT	STRAIGHT	LOW MID HIGH	0.00 1.07 0.00	0.00 0.00 0.00	0.00 0.00 0.00
>4-LANE	RURAL	LIGHT	UNLIT	STRAIGHT	LOW MID HIGH	0.00 1.34 0.00	0.00 1.51 0.00	0.00 0.00 0.00

Observer Indoctrination

Before the experiments began 6 AIL observers were taken on a complete tour of the road to familarize themselves with nodes, choice points, links, and sections of highway. Before the experiment, they were given a complete set of written instructions on the procedures to follow during the experiment. Basically, the role of the observer was to verify the route, operate the headlight selector switch, monitor the safety of the driver, and keep records of time, traffic, dimming requests, and beam usage.

Experiment Procedure

Evaluation sessions were run on the nights of September 5, 6, and 7, 1972. These midweek evenings were chosen to ensure that traffic composites for each evening would be comparable. There were no weather complications to bar the plans. Before the initial test runs, subjects were told about the session and given a familiarization period to learn the use of the systems and to gain experience driving the test vehicle. The subjects and observers were then assigned to vehicles on a random basis, not knowing what system their vehicles were equipped with.

Evaluation test runs were started at 8:00 p.m. Vehicles were dispatched in opposite directions on the test route at regular headways of 20 min. The headways were structured so that each vehicle would have at least 2 meetings opposite to every other test vehicle in the course of the test run. These meetings were time-phased to occur at different locations for each test run so that each system configuration would oppose each other system configuration on different roads and under different traffic and land use conditions. A series of forms were used in planning and operation—the nightly dispatch, observer, driver, and vehicle logs.

The test began with the observer instructing the driver on the procedures and allowing time for the driver to become acquainted with the vehicle. After driving started, the observer kept the details in the test-run log. At the end of the night's driving, each driver was given the daily evaluation questionnaire to fill out regarding the vehicle driven that night. At the end of the third night of experiments, each driver was given an additional questionnaire to fill out regarding the 3 nights and 3 different vehicles driven. This final debriefing summarized the 3 nights of driving.

Data Reduction and Analysis

In the head-lamp configuration evaluation, the objective responses generated by the observer and the subjective responses obtained from the drivers were measured.

Objective dependent variables included statistical tabulations of exposure to each independent variable and observed responses by the driver to these conditions. Subjective responses included using subject responses in-transit, ratings on a 7-point opinion scale, and responses to interviews.

Objective Responses—Both the observer's notes and the driver's subjective ratings were tabulated and a systems evaluation profile analysis (SEPA) was constructed. Initially, a set of 36 SEPA profiles—one for each driver's evaluation session—was constructed.

Once the single trial SEPAs had been constructed and compared, they were combined for each driver and for each forward lighting system. This combined SEPA, shown in Figure 4, is divided into the 6 road and land use segments defining the road categories at which the various beams are used. The data were reduced to a dimming request factor by accumulating all the dimming requests and the exposure time for each opportunity to use a beam mode. The utility of the beam configuration, from the SEPA, is thus reduced to comparing the dimming request factors for each beam mode and configuration. This figure is the most valid comparison because it uses the number of measured dimming requests as a function of the number of opportunities that vehicle had in that mode divided by an estimate of the time that beam is on for those circumstances. The dimming request factor is an inverse measure of the utility of each beam mode. The higher the number is, the worse the situation was.

The dimming request factor, however, did not prove to be a conclusive device for measuring efficiency of the beam configurations. In fact, combining the data for the high-beam mode from the 2-lane and 4-lane roads yielded factors of 29.00, 28.26, and 26.99 for dimming requests per vehicle-hour for the 2-3-2, 2-3-3, and 2-3-4 configurations respectively. These numbers indicate that the 3-beam configurations caused a similar number of dimming requests.

When the subject drivers were asked about glare from an approaching test vehicle, again they could not arrive at a consensus. The drivers did not know that there were different configurations of the 3-beam systems on the vehicles. The only thing they were sure of was that 3 headlights were lit on the midbeam mode. Each time they looked for the subject vehicle approaching from the opposite direction they would note if 3 headlights were visible. In no circumstances did they talk about excessive glare from the approaching cars. They were therefore more tuned to 3 headlights approaching than to overly bright lights.

Subjective Responses—A second measure of utility of the beam configuration was measured from the responses that each driver gave to 3 sets of questionnaires. One was given before the tests as a preevaluation questionnaire. One was given at the conclusion of each driving day to measure the effectiveness of that vehicle's beam configuration. A third and final briefing session requested a comparison of systems by each driver. In rating the headlight systems, a 7-point scale was used with numerical values of 1 for inadequate to 7 for excellent.

The results of the preevaluation questionnaire centered on the inadequacy of the headlights, especially on high-speed roads.

The first 4 questions of the daily evaluation questionnaire compared the 3-beam configuration with their present systems. The low beams on all the 3-beam systems were rated better than present systems, but the midbeams, high beams, and the overall headlight systems were rated at least 1 grade higher. The next 6 questions centered on the quality of the beam mode for different types of roads. The composite means of the 3-beam systems for all different road types in each beam mode were as follows:

Mode	Configuration		
	2-3-2	2-3-3	2-3-4
Low	4.25	3.94	3.92
Mid	5.48	5.01	4.58
High	5.17	5.62	5.67

There was a mean of about 4 (adequate) for the low beams, 5 (good) for the midbeams, and about $5\frac{1}{2}$ (between good and very good) for the high beams. There should have been no difference in responses in the low beams and midbeams for any of the configurations because all of the beam patterns were formed by the same type of head lamps. In the high-beam mode, the means of 5.67 and 5.62 were almost identical and were both greater than the 5.17 of the 2-3-2 configuration. This shows a slight preference for either the 2-3-3 or 2-3-4 configuration over the high-beam system composed of only 2 headlights.

The results of the final debriefing were inconclusive. The first question asked of the 6 drivers was whether they felt that a 3-beam system should be installed in all vehicles. Five out of 6 responded affirmatively. The next 3 questions asked the drivers to rank the performance of the low, mid, and high beams of the vehicles they had driven. The rating showed that there was no preference in headlighting systems. The ratings for the high beams (the only difference among the vehicles) were the same as the ratings for midbeams or low beams.

EMPIRICAL DETERMINATION OF SEEING DISTANCES

In the previous phase, the effectiveness of the system was determined by using subjective motorist and observer opinions. To complete the evaluation required an objective empirical determination of seeing distances. These data augmented and, in a sense, validated the subjective evaluations of the subjects.

Experiment Design

The procedure used to establish seeing distances was similar to that reported by Hull et al. (7) and Meese and Westlake (10). This procedure entailed setting up targets randomly on the side of the test course. Depending on the conditions (unopposed or with an opposing glare vehicle), the test vehicle was required to accelerate to a steady running speed of 40 mph. The driver would signal each time an obstacle was perceived. The observer in the vehicle recorded the distance.

Six subjects were used for all tests. They were randomly assigned a sequence in the test procedure for each of the test blocks shown in the test conditions. Similarly, the target position was randomly chosen for each block. Each block consisted of 2 trials for each subject, where possible, with the target position changed for each trial. In about 10 percent of the trials, the target was omitted, at random. But, when the target was omitted the subject was retested so that the readings from the trials could be completed within the block.

All seeing distance determinations were made at the Bridgehampton race track in Suffolk County, New York. This race track consists of suitable straight sections to enable simulation of all test conditions and to ensure safe testing. The track, designed for a Grand Prix race, has a straightaway of about 4,000 ft. This allowed enough distance for a vehicle to approach from the opposite direction and meet the test vehicle near the target.

The target selected for these tests was a 16-in. gray square plywood panel with 7 percent reflectivity. This target was selected because of its uniformity in shape and reflectivity and because of the even distribution of light over the whole surface.

The instrumentation for these tests (Fig. 5) was provided by Car and Driver magazine and consisted of a fifth wheel (Teston, model 1625), an electronic counter (Veeder-Root, model 771), and associated controls and wiring to determine the distance in feet. At the starting point, the counter was set at 0 and the driver was given a switch to stop the counter. At the starting signal, the driver accelerated to 40 mph and watched the possible target position. When the car began moving, the counter started reading the distance elapsed. The driver pressed the switch to stop the counter when the target was seen. Knowing the distance from start to the target position and knowing the distance from start to seeing the object, we determined the seeing distance.

Data Reduction and Analysis

Figure 6 shows the results of the experimentation. The group of bar graphs on the left represents the seeing distances for a case when the test car was driven without an opposing glare car. The group in the center represents the seeing distances when the instrumented car was opposed by a car approaching in the opposite direction with a 12-ft traffic lane separating the 2 vehicles (a 24-ft separation between the center of the cars). In all cases the glare car opposed the test car with the same beam mode and configuration. When the test car was on high beam with a 2-3-2 configuration, the glare car was also. The third group represents the seeing distances when the test car was opposed by the glare car approaching in an adjacent lane (a 12-ft separation between vehicles). Again, the glare car was in the same beam mode and configuration as was the test car. All the unopposed cases had sample sizes of 12 (repeated trial blocks), and the opposed trials had sample sizes of 6.

The first group, the unopposed cases, represents seeing distances on a straight, level, dark road. The low-beam case had a mean seeing distance of 198.9 ft, which was the result of improved low beams. The midbeam head lamp, an additional light on the driver's side of the vehicle, added more light straight ahead and farther down the road and increased the viewing distance to 253.6 ft. The high beam, 2-3-2 configuration, reduced seeing distance to 172 ft, and the high beam, 2-3-3 configuration, reduced seeing distance even lower (to 151.4 ft). This configuration, which had all its beams aimed at horizontal-vertical (0,0) and none down toward the road, should have added more light farther down the road but not much on the right shoulder. The high beam, 2-3-4 configuration, achieved the greatest seeing distances.

The low beams were aimed down to the right (½ deg vertically and 2 deg horizon-

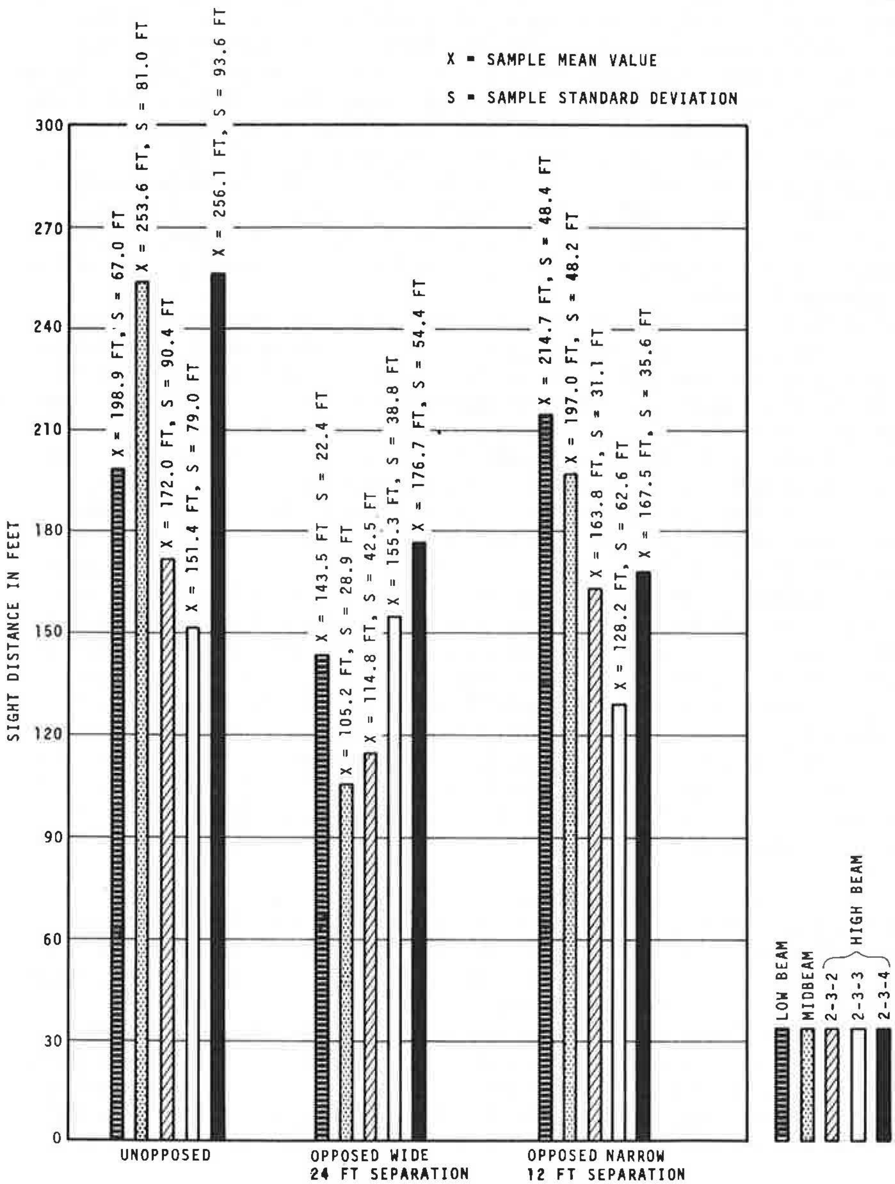
Figure 5. Sight distance experimentation.

starting gate and target

test vehicle with fifth wheel

instrumentation inside vehicle

Figure 6. Sight distance results.



tally). This sent more light to where the target was placed—5 ft to the right of the pavement edge. Because the midbeam was more concentrated and was also aimed low, the driver should have been further aided. But, the main effect of this beam was in the driver's lane and not off to the right. So, although a gain was noted because some light reached the target, the additional seeing distance was not overwhelming. The 2-3-2 high-beam configuration was the one in which some of the drivers and experts in the field noted a tunnel vision effect. Depth perception and visibility of the outside edges of the road were lost. This may have been the reason for the lower seeing distance in this case. The 3-light high beams should have been an improvement because the outside, low-beam head lamps filled in the picture the driver saw. However, the midbeam head lamp was not used, and this beam was aimed lower to the ground. The 4-light, high-beam configuration added the midbeam head lamp, and the best results in the unopposed category were achieved.

The second group of bars represents viewing distances in the presence of a glare car. This glare car accounted for the lower values of the sight distances for this group (an average of about 140 ft compared to 200 ft for unopposed). In the low-beam case the drivers saw an average of 143.5 ft, which is about 50 ft less than the unopposed low-beam case. This may have been because this was the first time the driver was exposed to an oncoming car in the tests. The unexpected value of these tests was in the midbeam mode (about 40 ft lower than the low beams). This result may also have been due to the unaccustomed driving in the presence of a glare car. Of course, with additional runs of the experiments, a more significant result may have been achieved. The 2-3-2, 2-3-3, and 2-3-4 high beams had seeing distances of 114.8, 155.3, and 176.7 ft respectively. The type 4 beam had little effect on either the midbeam mode or the 2-3-2 high-beam mode. Again, the 2-3-4 configuration had the highest seeing distance. These values may have been lower than the unopposed case because of the glare caused by the car approaching in the opposite direction.

The third group of bars represents viewing the object in the presence of a car approaching in the adjacent lane (12-ft vehicle separation). This group was lower than the unopposed case but higher than the opposed case with a wider separation. (The mean response was about 175 ft compared to 140 ft for the 24-ft separation case.) This group was higher than the previous one because, in general, the effect of the approaching car was to aid viewing of the target by a silhouette effect. The glare car, approaching the target, illuminated the background, gave the driver additional cues, and increased seeing distances. The low beams generated a seeing distance of 214.7 ft, which indicates that the driver was getting more accustomed to the road, the vehicle, the target-sighting switch, and the presence of an opposing glare car. The midbeam mode would have been expected to generate a slightly longer viewing distance than did the low beams, but the presence of a slightly more intense glare source may have caused the reduction. The main purpose of the midbeam head lamp was to add additional light in the center of the lane ahead of the driver. Therefore, even though there may have been additional light on the target, the driver was faced with slightly higher glare and, therefore, a reduced seeing distance. The high beams generated seeing distances of 163.8, 128.2, and 167.5 ft for the 2-3-2, 2-3-3, and 2-3-4 configurations respectively. Although these readings were made with a car approaching with its high beams on and, therefore, with higher glare, the expected results should have yielded longer seeing distances. The 2-3-2 and 2-3-4 configurations are about the same in value and are both larger than the 2-3-3 configuration.

The inconsistencies of the data can be attributed to limited scope and funding. At least 2 nights of trial runs, with and without a glare car and with all the beam configurations and modes, should have been completed before data were taken. And, when the data were taken, at least 3 trials for each task should have been tested, because 1 block (a sample size of 6) is insufficient for the results needed.

In addition, as shown in Figure 6, the unopposed trials have standard deviations varying from 67 to 94 ft. These values are much larger than those in the opposed trials where the deviations are in the 30s and 40s. This is partly due to the silhouette effect of the glare car in the opposed cases and partly because the unopposed trials were run first. That is, as the experiments proceeded, the drivers became more proficient.

CONCLUSIONS

From the data in the program and by discussions with many experts in the field, the 3-beam headlighting system is desirable and the 2-3-4 configuration is the best of the 3 tested.

Results of the analytic determination of glare brightness showed that the 2-3-4 and 2-3-3 configurations are similar and are both higher as glare producing agents than the 2-3-2 configuration. But, when these values are looked at in proper perspective—from the distances at which they will be used—they are very similar even though the 2-3-3 and 2-3-4 are slightly higher glare producers than the 2-3-2 is.

Subjectively, the drivers were unable to select 1 system as superior. Objectively, there were small differences in dimming requests by the opposing traffic. For the 3 configurations, the 2-3-4 had the fewest number followed by the 2-3-3 and 2-3-2. The last series of tests showed that the 2-3-4 had consistently better seeing distances than the other high-beam modes. So, the 2-3-4 is the proper configuration for a 3-beam headlighting system. (Adding a second filament to the low-beam head lamp is not difficult considering the lack of stringent requirements for this upper beam.) The 2-3-2 system is capable but results in a tunnel effect in the high-beam mode. The 2-3-3 system does not use the midbeam head lamp on its high-beam mode. Even though this beam might not add additional seeing distance in the mode, it does act to fill in the ground plane in front of the driver and again eases the driving task.

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